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EVALUATION OF A SULFUR DIOXIDE MASS EMISSION RATE MONITORING SYSTEM

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An evaluation was conducted to determine the capabilities and limitations of a commercially available monitoring system that provides sulfur dioxide mass emission rate data as a direct output. The monitoring system was operated continuously for extended periods at a coal-fired power plant and a sulfuric acid production facility. Additional testing was performed at a Simulated Stationary Source Facility to confirm some deficiencies noted during field operations. The system's performance was verified by comparing its output data with results using EPA emissions measurement reference methods.

Results are presented for three performance tests at both field sites. For the power plant tests, the monitor agreed within 20% of the accepted reference method. In the case of the acid plant, the system accuracy was as poor at 58%. Generally, the monitoring system performed reliably throughout the extended test program. The system remained operational greater than 90% of the time during the four-month test period.

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EVALUATION OF A SULFUR DIOXIDE MASS EMISSION RATE MONITORING SYSTEM

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ABSTRACT

An evaluation was conducted to determine the capabilities and limitations of a commercially available monitoring system that provides sulfur dioxide mass emission data as a direct output. The monitoring system was operated continuously for extended periods at a coal-fired power plant and at a sulfuric acid production facility. Additional testing was performed at a Simulated Stationary Source Facility to confirm some deficiencies noted during field operations. The system performance was verified by comparing its output data with the results obtained by EPA reference methods tests.

Results are presented for three performance tests at each field site. For the power plant tests, the monitoring system agreed within ± 20% of the accepted reference method. In the case of the acid plant, the system accuracy was as poor as 58 percent. Generally, the monitoring system performed reliably throughout the extended test program. The system remained operational greater than 90 percent of the time during the approximately 4-month test program.

This report covers a period from August 11, 1976, to July 1, 1977, and work was completed as of June 8, 1977.

CONTENTS

Abstract iii
Figures vi
Tables vi
Acknowledgements vii

1. Introduction 1

2. Conclusions 2

3. System Description 4
   Sample interface 4
   SO_2 analyzer 4
   Velocity subsystem 8
   Analog computer 8

4. Field Evaluation 10
   Test sites 10
   Test procedures 11
   Results and discussion 13

5. Stationary Source Simulator Tests 24
   Test facility 24
   Results and discussion 24

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FIGURES

Number		Page
1	Block diagram of the SO_2 mass emission rate monitoring system	5
2	Photograph of the monitoring system	6
3	Block diagram of the SO_2 analyzer	7

TABLES

Number		Page
1	Power Plant Test Data for Test Period #1.	14
2	Power Plant Test Data for Test Period #2.	15
3	Power Plant Test Data for Test Period #3.	16
4	Acid Plant Test Data for Test Period #1	18
5	Acid Plant Test Data for Test Period #2	19
6	Acid Plant Test Data for Test Period #3	20
7	Zero Drift Data for the SO_2 Analyzer	22
8	SSSF Test Data.	25
9	Zero Drift Data for SSSF Tests.	27
10	SO_2 and Emission Rate Values Data corrected for Zero Drift Errors	28

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The evaluation at the power plant as well as the first test series at the acid plant was conducted by Scott Environmental Technology, Inc. under EPA Contract No. 68-02-1400, Task 26. Additional testing at the acid plant was performed by Northrop Services, Inc. under EPA Contract No. 68-02-2566. Analyses of Method 8 samples obtained from the acid plant were made by Engineering-Science under EPA Contract No. 68-02-1406, Task 32.

SECTION 1

INTRODUCTION

The Emissions Measurement and Characterization Division of the Environmental Sciences Research Laboratory is engaged in programs to develop and evaluate measurement techniques and monitoring systems for pollutants emitted from stationary sources. Program activities include the evaluation of commercially available monitoring systems when a need is anticipated or known to exist. These activities are carried out primarily to support the implementation of performance standards for stationary sources.

According to regulations promulgated by the Environmental Protection Agency (EPA), certain stationary sources in designated industries must meet specific emission limitations. In addition to requiring these sources to comply with the emission limitations, EPA regulations call for continuous stack monitoring and the reporting of excess emissions on a mass-rate basis. Conventional monitoring systems provide emission data in terms of gas volume concentrations. This necessitates supporting measurements of volumetric flow rates and production rates in order to relate the concentration data to applicable standards. Errors may result if all measurements are not made concurrently.

More recently, the EPA has promulgated regulations that allow mass emission data to be calculated by using gas volume concentrations and predetermined conversion factors. The conversion factor would vary with plant operations but is assumed to remain relatively constant between successive determinations.

An alternate method for generating mass emission information is to use a monitoring system that provides real time mass emission rate data as a direct output. This approach should be more accurate and also greatly ease the burden of collecting emission data as required by EPA regulations.

This report presents the results of an evaluation of a commercially available monitoring system that provides sulfur dioxide (SO_2) mass emission rate data as a direct output. The monitoring system was designed for continuous monitoring applications at combustion sources. To determine system accuracy and reliability over an extended period, evaluations were conducted at a coal-fired power plant and at a sulfuric acid production facility. During the evaluation program, EPA reference methods were used to verify system performance.

SECTION 2

CONCLUSIONS

A monitoring system for sulfur dioxide (SO_2) mass emission rate (MERMS) has been successfully evaluated at a coal-fired power plant and at a sulfuric acid production facility.

The MERMS performed reasonably well during field operations at the power plant. For each of three test periods, the monitoring system agreed within 20% of the reference method. The mass emission rate errors were largely due to significant differences in both the SO_2 concentration and velocity measurements. In comparison with reference method values, the MERMS outputs were consistently 15-20% higher for SO_2 concentrations and about 10% lower for velocities. Since these percentage errors were nearly constant for all individual measurements, system accuracy can be improved by applying appropriate correction factors during calibration of the SO_2 analyzer and velocimeter subsystems.

During field operations at the acid plant, the MERMS relative accuracy was as poor as 58 percent. The poor performance was due primarily to severe zero drift in the SO_2 analyzer subsystem. Field tests for zero drift showed that the analyzer drift was typically 20-25 ppm per hour. The zero drifts were usually negative and thus resulted in lower SO_2 concentration readings. The zero drift problem was critical at the acid plant because of the low SO_2 concentration levels experienced during the test program.

An "automatic zero" option is available for the basic SO_2 analyzer used in the MERMS, but this optional feature was not incorporated in the system tested. It is likely that such an option may be necessary in order for the MERMS to meet current minimum performance specifications prescribed for monitors of SO_2 from stationary sources.

Despite the minimum attention provided, the MERMS operated reliably throughout the extended field test program. During almost 2 months of continuous operation at the power plant, the system required corrective maintenance actions on only two occasions. On one of these occasions, the problem was attributed to poor installation procedures rather than to a system weakness.

Upon installation of the MERMS at the acid plant site, a major malfunction occurred. The differential pressure sensor used in the velocity measuring subsystem was damaged when a backpurge solenoid failed, thus exposing the sensor to 50 psi of instrument air. Considering the delicate

nature of the pressure sensor, a more dependable method of switching backpurge air to the pitot lines should be incorporated. After becoming fully operational at the acid plant site, the MERMS operated continuously for over 2 months without any serious problem. Whenever a malfunction did occur, minimum efforts were required to diagnose and correct the problem.

It should be noted that the monitoring system tested was manufactured in 1972. The manufacturer claims that some modifications have been made to improve overall system performance. No attempt has been made to substantiate these claims.

SECTION 3

SYSTEM DESCRIPTION

The SO_2 Mass Emission Rate Monitoring System (MERMS) was manufactured by Western Research and Development, Ltd, Calgary, Alberta, Canada. It measures the effluent temperature, velocity, and SO_2 concentration independently and simultaneously. With these three measured variables plus appropriate constants, the system computes the instantaneous mass emission and volumetric flow rates on a continuous basis.

The system, shown schematically in Figure 1, has five basic subsystems: sample interface, SO_2 analyzer, velocimeter, temperature transmitter, and analog computer/remote control station. The measuring instrumentation is housed in two temperature-controlled enclosures designed to be located near the stack. The analog computer/remote control station was designed to be located in a control room. Photographs of the MERMS are shown in Figure 2.

The sample probe, sample line, and analyzer sample cell may be heated up to 250°C. Their temperatures are individually controlled by electronic circuitry which also provides automatic protection shutdown when any temperature falls outside a preselected range. Provisions are included for automatic backpurge of both the sample and Pitot lines. Calibration of the SO_2 analyzer and velocimeter may be performed from the remote control station.

SAMPLE INTERFACE

The sample interface consists of a combination probe assembly that incorporates a thermocouple, a Pitot tube, and a gas sample extraction probe. The gas sample probe is fitted with a sintered stainless steel filter for removal of coarse particulates. A heat-traced Teflon line connects the sample probe to the SO_2 analyzer. The probe assembly is 4 m long and about 7.6 cm in diameter.

SO_2 ANALYZER

The concentration of SO_2 in the sample is measured by a DuPont Model 400 Photometric Analyzer. This analyzer, shown schematically in Figure 3, is a dual beam single path instrument utilizing the principle that gases absorb radiation at characteristic wavelengths. Light from an ultraviolet source, after passing through a sample cell, is split into a reference and a measuring beam. These beams are directed through appropriate bandpass filters before reaching the detectors. The wavelength of the measuring beam filter is selected for strong absorption by SO_2 while the reference wavelength is selected from minimum absorption by SO_2. The analyzer used in the MERMS

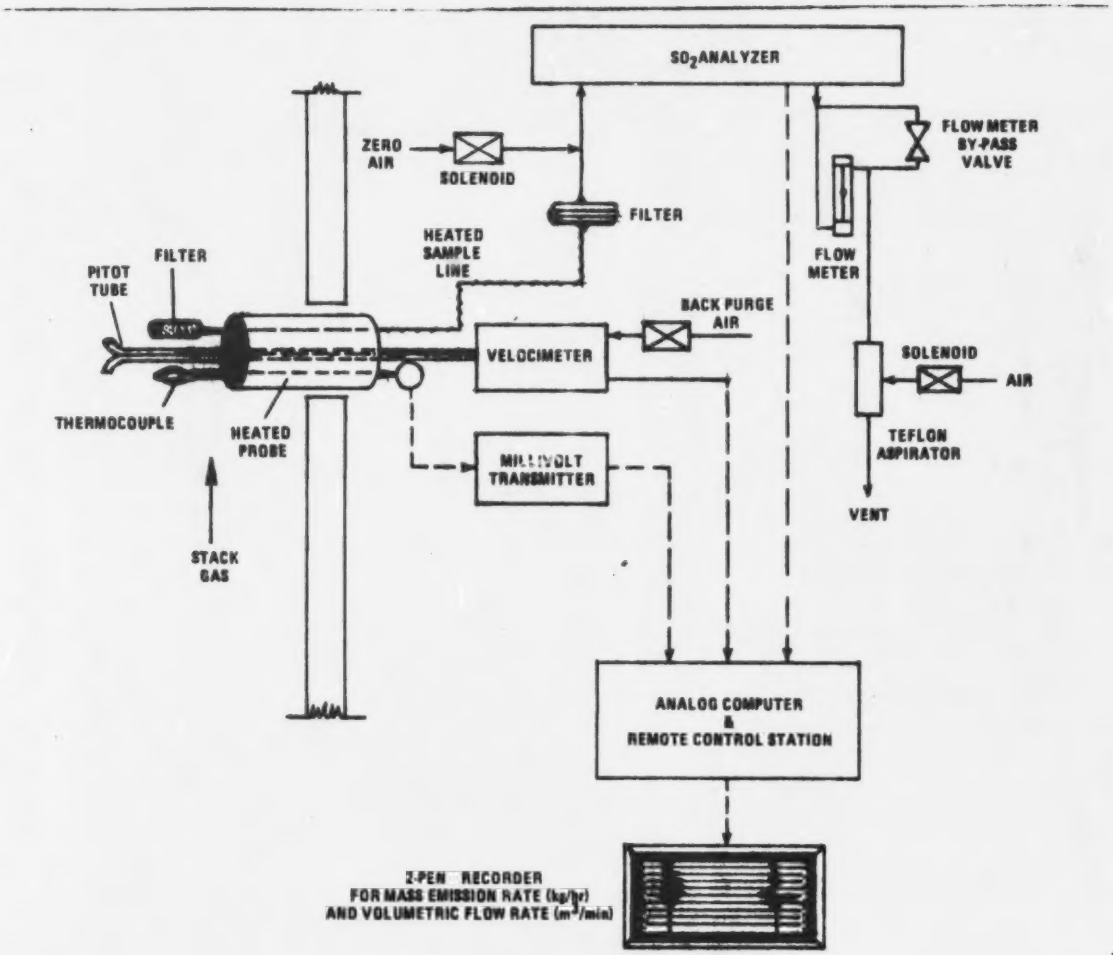

Figure 1. Block diagram of the SO_2 mass emission rate monitoring system

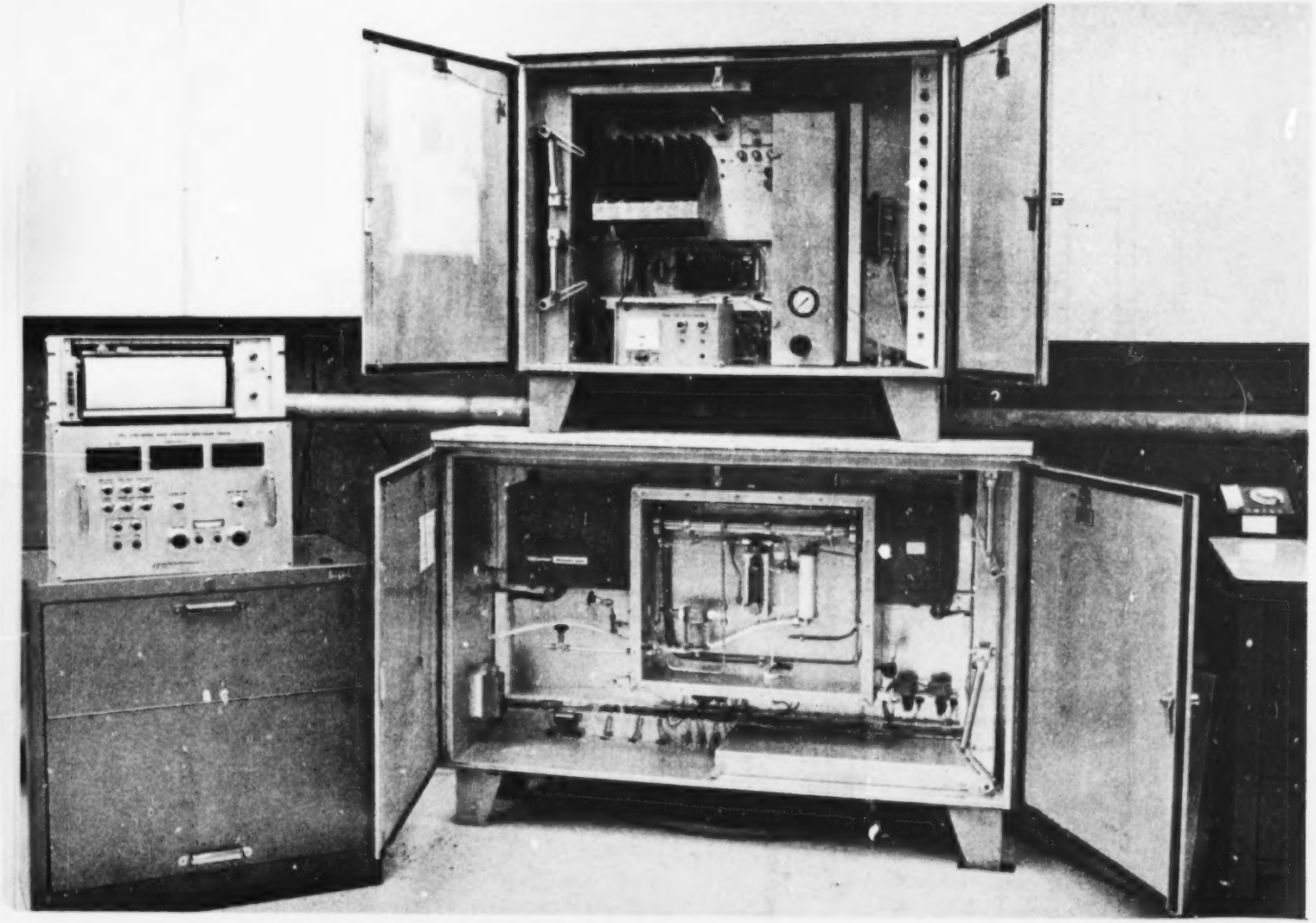

Figure 2. Photograph of the monitoring system

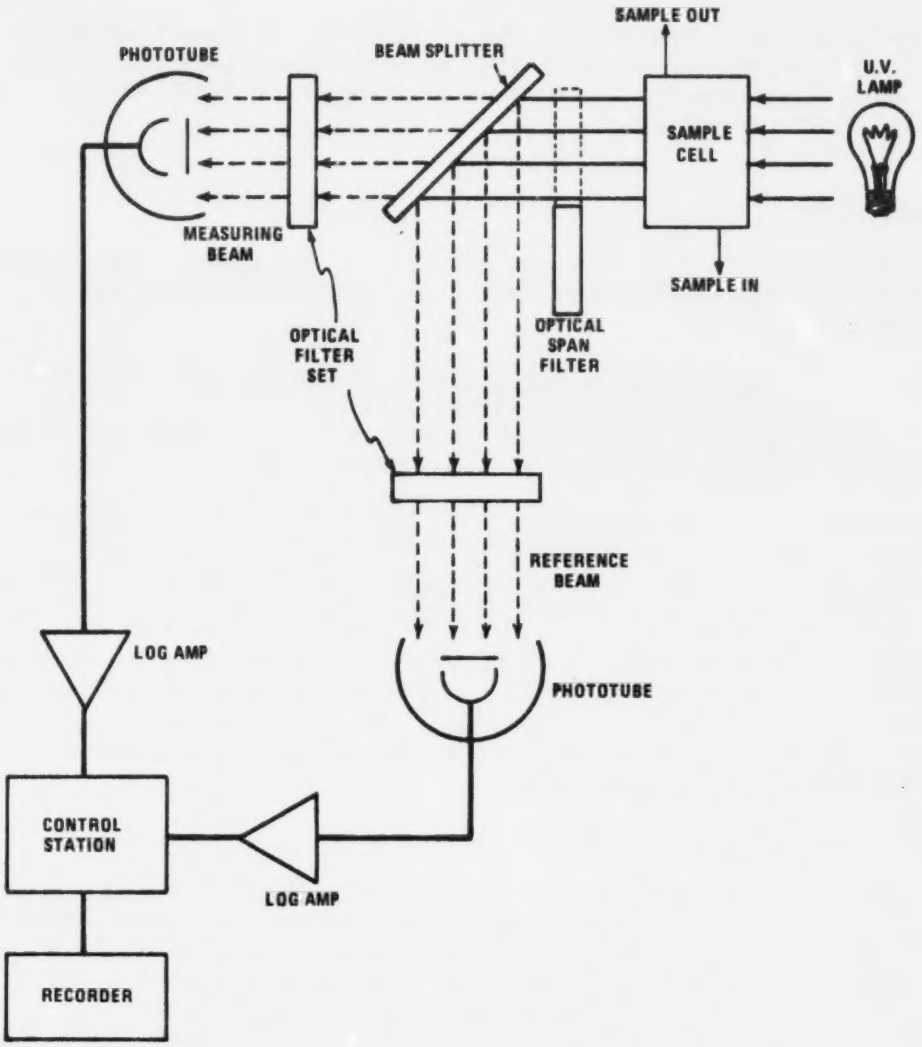

Figure 3. Block diagram of the SO_2 analyzer

employs a measuring wavelength of 280 nm and a reference wavelength of 578 nm. The output from each detector is amplified, and the difference between their signals is proportional to the SO_2 concentration in the sample.

The sample gas is pulled through the analyzer by an air-driven Teflon aspirator. The analyzer may be calibrated by introducing into the sample cell a gas whose concentration is known or by using an optional optical filter to simulate a known concentration.

VELOCITY SUBSYSTEM

Continuous measurement of effluent velocity is accomplished by measuring both the effluent temperature and velocity head near the point at which the sample is extracted.

Temperature is measured by a Type J (iron-constantan) thermocouple interfaced with a Leeds & Northrup temperature/millivolt transmitter. This instrument is a solid state amplifier whose output varies linearly with the millivolt signal from the thermocouple in the probe assembly.

The velocity head is measured by an "S" type Pitot tube coupled with a Western Research & Development Model 301 Velocimeter. The velocimeter employs a differential pressure sensor and converts the differential pressure measured by the Pitot tube into an electrical signal.

The temperature transmitter is calibrated by disconnecting the thermocouple inputs and using a millivolt source to simulate zero and span voltages as read from a thermocouple conversion chart. The velocimeter is calibrated by applying a known differential pressure at the pressure transducer and making suitable electronic adjustments.

ANALOG COMPUTER

The analog computer receives the input signals representing SO_2 concentration, differential pressure, and temperature. With these three variables plus appropriate constants, the effluent velocity, volume flow rate and pollutant mass emission rate are calculated on a continuous basis. Adjustments for required constants, including barometric pressure, specific gravity, pitot factor, and stack cross-sectional area, are made on the front panel.

Analog signals representing volume flow rate and mass emission rate are available for strip chart recording. The continuous status of SO_2 concentration, temperature and velocity are displayed on digital panel meters on the front panel. Analog outputs are also available for these three readouts.

The computer is calibrated by using a digital voltmeter to adjust various circuit components to provide specified values at given test points. A check of computer operation is then made by introducing simulated inputs and comparing the outputs with precalculated results.

The computer is programmed to solve the following equations:

$$V_s = 4.8415 \times P_f \times \sqrt{\frac{D.P. \times Ts}{SG \times P_s}} \qquad (1)$$

$$Q_s = 5145.715 \times P_f \times A \times \sqrt{\frac{D.P. \times Ps}{SG \times T_s}} \qquad (2)$$

$$E_m = 0.8192 \times C_{SO_2} \times P_f \times A \times \sqrt{\frac{DP \times Ps}{SG \times T_s}} \qquad (3)$$

where: V_s = Effluent velocity (at stack conditions) in m/sec

Q_s = Volume flow rate (at standard conditions) in m^3/min

E_m = Mass emission rate (at standard condition) in kg/hr

P_f = Pitot factor (may include a profile factor)

D.P. = Differential pressure in inches of H_2O

T_s = Stack temperature in ^oR

SG = Specific gravity of effluent (ratio of the molecular weight of the effluent to air)

P_s = Absolute stack pressure in inches of Hg

A = Cross-sectional area of stack in m^2

C_{SO_2} = SO_2 concentration in ppm

The basic monitoring system may be custom designed to meet specific requirements. The system manufactured for the EPA was designed for the following conditions:

Mass Emission Rate	0-15,920 kg/hr (at standard conditions)
Volume Flow Rate	0-100,000 m^3/min (at standard conditions)
Velocity	0-30 m/sec (at stack conditions)
SO_2 Concentration	0-1000 ppm (on a wet basis)
Differential Pressure	0-2.5 inches H_2O
Temperature	30^o-250^oC
Area (Stack)	0-100 m^2

SECTION 4

FIELD EVALUATION

TEST SITES

Field testing of the MERMS was conducted at a power plant and at a sulfuric acid procudtion facility, both located in the south eastern United States.

The power plant unit was used primarily during peak load periods and had a capacity for generating approximately one million pounds of steam per hour which produced about 150 MW of electrical power. Emissions from the coal-fired boiler was controled by cyclones located after the economizer followed by a Buell electrostatic precipitator located after the air heaters. An induced draft fan, following the precipitator, exhausted the effluent gases through a 60-meter high concrete stack. Stack conditions at the sampling point were as follows:

Temperature	∿115°C
Moisture	∿7%
SO_2 Concentration	500-800 ppm
O_2 "	5-6%
CO_2 "	12-13%
CO "	∿0%
Velocity	12-14 m/sec
Static Pressure	∿-10 in H_2O
Area (Stack)	8.55 m^2

The MERMS probe was located in a 1.2-m x 7.5-m duct on the outlet of the electrostatic precipitator. The instrumentation, including remote control station, was located near the duct and on a platform under the precipitator hoppers.

The sulfuric acid facility was a conventional double absorption/double contact process plant burning elemental sulfur. The unit was designed for a converter inlet SO_2 concentration of 10 percent and a production capacity of

1500 tons of acid per day. Control of sulfur compound emissions involves recycling gases from a first absorption tower through catalytic stages before going to the final absorber. Mist eliminators are installed in the absorption towers for removal of any acid mist. Stack conditions at the sampling point were as follows:

Temperature	70^{o}-80^{o}C
SO_2 Concentration	50-200 ppm
Velocity	27-31 m/sec
Moisture	~0%
Static Pressure	~1 in H_2O
Area (Stack)	2.14 m^2

The MERMS probe was located in a 2-m circular stack following the final absorption tower. Sampling ports were about 2 m below stack exit. The instrumentation was located on an unsheltered platform 6 m below the sampling ports. The remote control station and data recorders were located in a small room at ground level.

TEST PROCEDURES

The monitoring system was operated continuously from August 9, 1976, through October 8, 1976, at the power plant and from January 5, 1977, through March 19, 1977, at the acid plant.

Reference methods 6 and 8 were conducted at the power plant and acid plant, respectively. At both facilities, the reference tests were performed during three test periods, separated by approximately 2-weeks, intervals. Between performance test periods, the monitoring system operated unattended. Plant personnel checked the system occasionally to confirm that it was operational. Maintenance actions were performed only after it became obvious that a malfunction had occurred. No attempt was made to validate data generated or system performance during periods of unattended operation.

Performance test procedures were based on those specified in "Performance Specifications and Specifications Test Procedures for Monitors of SO_2 and NO_x from Stationary Sources", Federal Register, Volume 40, Number 194, October 6, 1975. Some of the prescribed test procedures were slightly modified to accommodate the MERMS and plant operations. For example, specified procedures for zero and span are based upon a system whose output is in terms of volume concentration. With the MERMS, zero and span checks/adjustments are performed for each subsystem independently rather than for the system as a whole. The regulations also stipulate that no more than one reference measurement shall be performed in any one hour. However, due to the limited and uncertain operating schedules of the power plant boiler, sampling times were abbreviated to allow for a maximum number of samples during a test period.

At the power plant, field tests for zero and span drift were not performed because of the brief time period available for each test series. A performance test period was generally conducted during an 8-to-10 hour span and thus did not allow for the accumulation of enough drift data to be conclusive.

Single point sampling was employed throughout the test program. To insure that possible stratification had no effect on comparative test data, the reference and monitor probes were positioned less than 8 cm apart. For the power plant tests, the reference probe was attached to the monitor probe and shared a common port. For the acid plant test, the reference probe was located in an adjacent port. The probes could be seen through another port and positioned so that all probes sampling the same area in the stack.

At both facilities, the MERMS spans for SO_2 concentration, temperature and velocity were set at their designed full-scale ranges. Spans for mass emission rate and volumetric flow rate were set at 1592 kg/hr and 10,000 m^3/min, respectively. These values were based upon maximum expected outputs as determined by preliminary site measurements. The monitor probe and sample line operating temperatures were 125°C at the power plant and 95°C at the acid plant. The SO_2 analyzer sample cell was operated at 125°C at both test sites.

Following initial setup at both facilities and at the beginning of each performance test period, the MERMS was calibrated according to manufacturer's instructions. The nature of the system dictates that each subsystem be calibrated separately and independently.

The SO_2 analyzer was first calibrated with blends of 549 and 964 ppm SO_2 in nitrogen and nitrogen zero gas. Instrument responses were adjusted for the sample cell pressure difference between sample and calibration modes. An internal optical filter is incorporated in the monitor for checking the calibration remotely without gases. The simulated SO_2 concentration given by insertion of this filter was determined relative to the span gas responses during original calibration. This span filter was then used for calibration checks throughout the remainder of the performance test period.

The velocimeter was initially calibrated by applying known differential pressures at the pressure sensor. A syringe was used as the source, and the pressure was read on an inclined water manometer. The velocimeter also incorporates provision for remote calibration by electronically simulating a known differential pressure. This simulated pressure response was then related to the initial calibration responses and used for calibration checks during the Pitot tube in the calibration. A Pitot calibration factor had been established in the laboratory prior to commencing the field test program.

The temperature transmitter was calibrated by disconnecting the thermocouple inputs and using a millivolt source to simulate zero and span voltages

as read from a thermocouple conversion chart. Appropriate electronic adjustments were made to produce proper output voltages.

Computer operations were checked at the beginning of each performance test period by introducing simulated inputs and comparing the outputs with precalculated results. A complete calibration of this subsystem was necessary only upon initial installation at each test site and involved making electronic adjustments to give specified voltage readings.

With the system calibrated and continuously recording data, concurrent measurements of SO_2 concentration, effluent velocity, and temperature were performed according to EPA reference methods procedures. At the power plant, EPA Reference Method 6 tests for SO_2 concentration were run for about 15 min each, during which approximately 1 ft^3 of sample was collected. At the acid plant, EPA Reference Method 8 tests were run for 40 min, collecting about 35 ft^3 of sample.

In addition to recording the MERMS primary outputs of mass emission and volume flow rates, the SO_2 concentration and velocity outputs were also continuously recorded for informational purposes. The monitor temperature output was periodically read from the digital panel meter and logged for future reference.

RESULTS AND DISCUSSION

Performance test results are listed in Tables 1-3 for the power plant and Tables 4-6 for the acid plant. All MERMS outputs, except temperature, were read from strip chart recordings. The values shown for MERMS temperatures are approximations in that the temperature was not continuously recorded. Reference method SO_2 concentrations, velocities, and volume flow rates were calculated according to procedures outlined in the Federal Register, Volume 36, Number 247, December 23, 1971.

Power Plant Tests

Tables 1, 2, and 3 show the data obtained during testing at the power plant during the three test series. The values for SO_2 concentration, volume flow rate and emission rate are reported on a wet basic and at standard conditions. For all samples, mass emission rates determined by the monitor were higher than those calculated from reference methods data. Analyses of the raw data show that the SO_2 concentration was the variable primarily responsible for these differences. For each of the three test periods, the MERMS SO_2 concentrations were about 15-20% higher than the corresponding reference method values. It is also evident that a consistent disagreement existed between velocity values as determined by the two methods. The MERMS velocities ran about 10% lower than reference method values. Since the emission rate is directly proportional to both SO_2 concentration and velocity, the low velocity values offset the high SO_2 values, resulting in good agreement between emission rate values.

TABLE 1. POWER PLANT TEST DATA FOR TEST PERIOD #1

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.*	MERMS	Ref.	MERMS	Ref.	MERMS**
9/1/76	1-1	174	248	2954	2840	370	538	6.9	6.5	83	74
"	-2	230	307	3000	2954	483	643	7.1	6.7	87	75
"	-3	452	515	4818	4575	589	713	11.9	10.9	100	88
"	-4	379	492	4937	4550	482	678	12.5	11.3	110	96
"	-5	474	510	5148	4700	578	660	13.2	11.8	115	110
"	-6	496	530	4973	4940	627	665	12.8	12.5	116	113
"	-7	428	527	5127	5075	525	641	13.1	13.1	116	113
"	-8	426	521	5071	5075	528	619	13.0	13.1	116	113
9/2/76	-9	602	617	5219	4930	724	772	13.5	12.7	118	113
"	-10	593	655	5346	5050	697	802	13.7	13.0	116	116
"	-11	661	670	5399	5000	769	820	13.8	13.1	116	116

*Corrected to 7.0% H_2O

**Approximate value

TABLE 2. POWER PLANT TEST DATA FOR TEST PERIOD #2

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.*	MERMS	Ref.	MERMS	Ref.	MERMS**
9/21/76	2-1	391	459	5292	4700	464	600	14.3	12.8	120	116
"	-2	376	451	5400	5093	437	550	14.6	13.7	120	116
"	-3	328	393	4907	4700	420	517	13.2	12.9	120	116
"	-4	394	459	5414	5230	458	538	14.3	14.0	113	116
"	-5	378	450	5473	5250	434	525	14.5	14.1	113	116
"	-6	430	482	5301	5090	510	588	14.0	13.6	112	113
"	-7	387	447	5057	5075	481	545	13.4	13.5	112	113
"	-8	400	447	5407	5230	465	533	14.3	13.9	113	113
"	-9	411	462	5376	5250	480	542	14.2	14.0	112	113
"	-10	412	465	5416	5250	478	550	14.4	14.3	116	113

*Corrected to 7.0% H_2O

**Approximate value

TABLE 3. POWER PLANT TEST DATA FOR TEST PERIOD #3

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.*	MERMS	Ref.	MERMS	Ref.	MERMS**
10/6/76	3-1	483	490	5768	5500	524	551	14.7	14.4	122	119
"	-2	446	462	5450	5270	512	559	13.9	13.4	121	119
"	-3	446	490	5501	5230	507	577	14.0	13.6	121	119
10/7/76	-4	512	574	5684	5487	563	650	14.3	14.0	117	116
"	-5	508	567	5651	5387	562	648	14.3	13.9	118	116
"	-6	466	542	5294	5106	550	653	13.4	13.1	120	116
"	-7	476	523	5077	4806	586	679	12.8	12.6	119	116

*Corrected to 7.0% H_2O

**Approximate value

System relative accuracy data for the three power plant test periods is summarized below.

Test Period Number	Mean Reference Value(kg/hr)	Absolute Mean Difference(kg/hr)	95% Confidence Interval(kg/hr)	System Relative Accuracy
1	446.8	61.5	22.0	18.7%
2	390.7	60.8	6.9	17.3%
3	476.7	44.4	23.1	14.2%

Relative accuracy is reported as the sum of the absolute value of the mean difference and the 95% confidence interval of the differences expressed as a percentage of the mean reference method value. All three of the results are better than the 20% value currently specified as minimum performance specification for monitors of SO_2 from stationary sources.

Field tests for zero and span drift were not performed during testing at the power plant. However, general observations revealed a potential analyzer drift problem. The MERMS has four major components subject to drift: the SO_2 analyzer, velocimeter, temperature transmitter, and computer. Of these, the SO_2 analyzer was the only component observed to be prone to significant drift, primarily zero drift. This was exemplified by the drift adjustments required before and after each performance test period. Zero drift for other components and span drift for all components were noted to be minimal, even after several days of unattended operations.

The operational period was greater than 168 hr for each test period at the power plant. In fact, during the almost 2-months program, only two incidents occurred that required corrective maintenance action. On the first occasion, the sample probe temperature sensor failed, causing the system to automatically shut down when the operating temperature fell below set-point. The second failure was caused by the temperature sensor not making good physical contact with the probe and again triggering automatic shutdown. Both of these problems were easily diagnosed and corrected, resulting in minimum system downtime.

Acid Plant Tests

Tables 4, 5, and 6 show the test data obtained during testing at the acid plant. The first series of tests were performed on the first day following system setup and thus before the normal 168-hr conditioning period. During this test period, the MERMS emission rate values compared favorably with the reference method values. However, during the second and third test periods, the monitor did not perform as well. The combination of low SO_2 concentrations and low velocities resulted in significant disagreement between emission rate values.

TABLE 4. ACID PLANT TEST DATA FOR TEST PERIOD #1

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS*
1/4/77	1-1	74.4	85.0	3292	3110	142	157	30.6	28.7	79	79
"	-2	71.3	81.9	3292	3200	136	160	30.6	28.6	79	79
"	-3	78.3	80.9	3323	3200	148	157	30.9	29.2	79	79
"	-4	80.4	78.7	3323	3200	152	155	30.9	29.2	79	79
1/5/77	-5	77.8	83.1	3323	3200	147	160	30.9	29.4	79	79
"	-6	73.0	81.9	3323	3075	138	164	30.9	28.1	79	79
"	-7	76.5	81.9	3292	3150	146	160	30.6	20.1	79	79
"	-8	73.4	81.9	3292	3200	140	157	30.6	29.3	79	79
"	-9	81.8	78.7	3292	3150	156	153	30.6	29.0	79	79

*Approximate value

TABLE 5. ACID PLANT TEST DATA FOR TEST PERIOD #2

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS*
2/23/77	2-1	48.4	47.8	2962	2540	103	116	27.6	24.5	77	70
2/24/77	-2	55.0	62.6	2991	2602	115	132	28.4	22.2	76	75
2/25/77	-3	53.7	55.5	3022	2601	112	160	28.2	24.5	75	75
"	-4	57.4	51.5	3022	2570	120	132	28.2	24.5	75	75
2/26/77	-5	52.4	32.8	3013	2570	110	84	28.3	24.8	77	75
"	-6	48.6	51.7	3015	2655	102	120	28.2	24.1	77	75
"	-7	39.2	33.0	3012	2655	82	84	28.3	24.4	78	75
"	-8	46.9	19.0	3015	2680	98	44	28.2	.2	77	75
"	-9	50.1	13.6	3015	2697	105	32	28.2	24.1	77	75

*Approximate value

TABLE 6. ACID PLANT TEST DATA FOR TEST PERIOD #3

DATE	Sample #	Emission Rate (kg/hr)		Flow Rate (m3/min)		SO_2 (ppm)		Vel (m/sec)		Temp (^oC)	
		Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS*
3/18/77	3-1	28.4	26.9	2942	2553	61	76	27.8	23.6	76	75
"	-2	26.6	18.8	2942	2553	57	48	27.8	23.2	76	75
"	-3	37.1	13.6	2942	2553	79	48	27.8	23.4	76	75
"	-4	32.2	13.6	2800	2590	72	44	26.5	23.4	76	75
"	-5	34.8	13.6	2800	2590	78	44	26.5	23.4	76	75
3/19/77	-6	30.8	29.9	2881	2511	67	88	26.9	22.8	73	75
"	-7	29.3	27.3	2881	2494	64	80	26.9	22.8	73	75
"	-8	38.1	25.9	2881	2494	83	76	26.9	22.5	73	75

*Approximate value

System relative accuracy data for these three test periods is summarized below:

Test Period Number	Mean Reference Value(kg/hr)	Absolute Mean Difference(kg/hr)	95% Confidence Interval(kg/hr)	System Relative Accuracy
1	76.3	6.2	2.9	11.7%
2	50.2	12.5	9.6	43.9%
3	35.2	11.0	7.5	57.5%

Again, the SO_2 concentration was the variable primarily responsible for the poor system accuracy. Note that for samples 2-5, -8, -9 (Table 5) and samples 3-2, -3, -4, -5, -8 (Table 6), the MERMS SO_2 values were considerably lower than the corresponding reference method values. These measurements were made a few hours after daily zero adjustments and include large errors due to severe zero drift in the SO_2 analyzer.

Table 7 shows the zero drift data obtained for the SO_2 analyzer during two test periods. Both 2 hr drift results exceed the 2% value specified for continuous monitors of SO_2 from stationary sources. Note that the amounts of zero drift experienced were of the same order of magnitude as the average SO_2 concentration levels during the testing. Zero drift for other subsystems and span drift for all subsystems, including the SO_2 analyzer, were observed to be negligible throughout the acid plant test program.

Upon installation of the MERMS at the acid plant site, a major breakdown occurred. The differential pressure sensor in the velocimeter was damaged when a backpurge solenoid malfunctioned and allowed 50 psi of instrument air to damage the sensor. The sensor was removed and returned to the manufacturer for repair. After replacing the pressure sensor and returning the system to operation on January 5, 1977, no other major malfunction was experienced through completion of the test program on March 19, 1977.

Some minor problems were encountered during the first part of the test program. Most of them involved the system's temperature controllers. In one instance, it was found that during some backpurge cycles the cold instrument air cooled the sample probe below the set-point and resulted in automatic system shutdown. This problem was solved by simply decreasing the probe temperature from 125°C to 95°C. On other occasions, a faulty cabinet heater apparently contributed to erratic responses by the temperature control electronic circuitry, usually during periods of severe cold weather. After replacing the defective heater with a heat lamp, these problems disappeared.

One recurring problem was experienced throughout the acid plant test program. This problem was due to the water-logged signal cable harness that

TABLE 7. ZERO DRIFT DATA FOR THE SO_2 ANALYZER

Date	2 hr Δ Z (ppm)	4 hr Δ Z (ppm)	
2/23	-30	-30	2 hr
	0		Mean difference = 31.1 ppm
2/24	-23		95% Confidence Interval = 11.83 ppm
2/25	-46	-70	Drift (% Span) = 4.3%
2/26	-24		4 hr
	-24		Mean difference = 61.3 ppm
	-50	-84	95% Confidence Interval = 51.5 ppm
	-46		Drift (% Span) = 11.3%
	-37		
3/18	-46	-58	2 hr
	-12		Mean difference = 24.8 ppm
	-30	-30	95% Confidence Interval = 17.75 ppm
	0		Drift (% Span) = 4.3%
3/19	-42	-61	4 hr
	-19		Mean difference = 49.7 ppm
			95% Confidence Interval = 31.4 ppm
			Drift (% Span) = 8.1%

connected the measuring instrumentation to the remote control station. During initial setup of the MERMS, a portion of the cable harness had been left lying on the floor of the building where the analog computer/remote control station was located. Upon return to the test site a few days later, the cable was found submerged. This condition contaminated the signal cables and resulted in leakage between signals being fed to the computer. The temperature signal input was the only one noticeably affected.

The remaining problems were caused by the hostile environment of an acid plant. Corrosion of some components necessitated frequent cleaning and, in one case, the replacement of the thermocouple connector and wire. After about 30 days of operation, the Pitot tube became clogged with a greenish, clay-like substance from the effluent. This substance also accumulated on the probe filter element. Backpurge of the Pitot and sample lines did not effectively remove this substance.

SECTION 5

STATIONARY SOURCE SIMULATOR TESTS

During the period of June 1-8, 1977, the MERMS was further evaluated at the EPA Stationary Source Simulator Facility (SSSF). This test program was conducted to confirm system deficiencies noted during the field evaluation. Tests for relative accuracy, zero drift, and span drift were performed.

TEST FACILITY

The SSSF is basically a closed-loop wind tunnel with provisions for providing tailored and well-controlled air pollutant atmospheres. Controllable parameters include gas stream velocity, temperature, particulate size and loading, humidity, and gas concentration. The tunnel test section is fitted with a number of ports to allow for sampling using EPA reference methods and various types of monitors. A complete description of the SSSF may be found in the report, EPA-650/2-75-015, Fabrication and Installation of the Stationary Source Simulator, January 1975.

The SSSF was operated to simulate acid plant conditions. The SO_2 concentration was varied from 50-150 ppm while maintaining the temperature and velocity at approximately 75 °C and 25 m/sec, respectively. Cylinders of pure SO_2 were used to charge the tunnel to desired levels. Gas concentrations were maintained by manual control of injection values. EPA reference method tests were performed to establish actual SO_2 concentration levels and gas stream velocities. The reference and MERMS probes were located in opposing ports on the first test section. The stack cross-sectional area at the sampling point was approximately 0.557 m^2.

The MERMS was set up, calibrated, and left running continuously for a 7-day period. Zero and span adjustments were made at the beginning of each test day. The SSSF was operated only during the normal 8-hr work day.

RESULTS AND DISCUSSION

Table 8 shows the data obtained during testing of the MERMS at the SSSF. As noticed during the field test program, the monitoring system SO_2 concentrations were consistently higher and velocities lower than corresponding reference values. Relative accuracy data is enumerated below for each of the recorded outputs.

TABLE 8. SSSF TEST DATA

Date	Sample	Emission Rate (kg/hr)		Flow Rate (m^3/min)		SO_2 Conc. (ppm)		Velocity (m/sec)		Temperature* (°C)
		Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	Ref.	MERMS	
6-1-77	1	10.4	11.2	627.5	620	106	110	22.4	21.9	74
	2	10.2	13.1	627.4	600	103.7	131	22.4	21.5	74
	3	10.4	15.7	626.5	620	105.3	153	22.4	21.9	74
	4	10.3	15.7	625.5	610	105.3	153	22.5	21.8	76
6-2-77	5	5.6	6.7	627.7	620	56.6	61	22.4	21.9	74
	6	4.2	8.1	628.3	620	42.2	77	22.4	21.9	73
	7	9.2	11.3	625.2	610	93.5	108	22.5	21.9	76
6-6-77	8	6.3	9.4	620.7	600	64.7	90	22.3	21.4	74
	9	11.9	17.6	613.8	580	123.1	180	22.1	20.0	74

* Average temperature measured by the MERMS and used in the reference calculations

System Output	Mean Ref. Value	Mean Difference	95% Confidence Interval	Relative Accuracy
Emission Rate (kg/hr)	8.7	3.36	1.39	54.6%
Volume Flow Rate (m^3/min)	624.7	15.8	7.35	3.7%
SO_2 Concentration (ppm)	100.6	18.6	10.32	28%
Velocity (m/sec)	22.4	0.7	0.19	4%

The poor relative accuracy for emission rate was due largely to the SO_2 variable. As expected, the SO_2 analyzer zero drift performance accounted for much of the error noted. Table 9 shows the drift data obtained for the SO_2 analyzer during the test period. Note that the 2-hr zero drift was better than the 2% value currently specified for SO_2 monitors. Table 10 shows the monitor SO_2 and emissions rate values corrected for approximate zero drift errors. Relative accuracy determinations using these corrected values are snown below.

	SO_2 Concentration, corrected for zero drift	Emission Rate, corrected for zero drift
Mean Ref. Value	100.6 ppm	8.7 kg/hr
Mean Difference	8.1 ppm	1.2 kg/hr
95% Confidence Interval	3.4 ppm	0.34 kg/hr
Relative Accuracy	11.5%	17.6%

These results show that despite being relatively small, zero drift errors seriously affected system accuracy.

TABLE 9. ZERO DRIFT DATA FOR SSSF TESTS

DATE	TIME	2 hr $\Delta\bar{z}$ (ppm)
6-1-77	0930 - 1130	+7
	1130 - 1330	+10
	1330 - 1530	+11
	1530 - 1730	+13
6-2-77	0830 - 1030	+5
	1030 - 1230	+11
	1230 - 1430	-3
	1430 - 1630	-13
6-3-77	0815 - 1015	-18
	1015 - 1215	+23
	1215 - 1415	+2
	1415 - 1615	+8
6-6-77	0815 - 1015	-2
	1015 - 1215	-14
6-7-77	0815 - 1015	-17

Mean Zero Drift (2 hr) = 10.5 ppm
95% Confidence Interval = 3.4 ppm
Drift (%Span) = 1.4%

TABLE 10. SO_2 AND EMISSION RATE VALUES CORRECTED FOR ZERO DRIFT ERROR

Sample #	MERMS Outputs SO_2 (ppm)	MERMS Outputs E_m (kg/hr)	Approximate Zero Drift Error (ppm)	SO_2 Corrected for Zero Drift (ppm)	E_m Corrected for Zero Drift (kg/hr)
1	110	11.2	+2	108	11.0
2	131	13.1	+16	112	11.2
3	153	15.7	+35	118	12.1
4	153	15.7	+35	118	12.1
5	61	6.7	---	61	6.7
6	77	8.1	+20	57	6.0
7	108	11.3	+8	100	10.5
8	90	9.4	+20	70	7.3
9	180	17.6	+50	130	12.7